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# A novel educational tool for teaching diagnostic reasoning and laboratory data interpretation to veterinary (and medical) students.

## Abstract

The Diagnostic Pathfinder was designed to help students learn diagnostic problem solving by supporting them in explaining relationships among history and physical examination findings, data abnormalities, and the underlying mechanisms of disease. The Pathfinder has been used to teach diagnostic problem solving to veterinary students since 2001 and is currently in use at 10 colleges of veterinary medicine. This article describes how the Pathfinder works and summarizes results from studies exploring the effect of Pathfinder use on learning and satisfaction. Pathfinder characteristics are described in terms of their influence on cognitive load, and strategies are provided for effective implementation.

## Keywords

Clinical pathology, Case based learning, Problem solving, Diagnostic reasoning, Expert thinking, Cognitive tool, Learning, Software design and development

## Disciplines

Comparative and Laboratory Animal Medicine | Other Veterinary Medicine | Veterinary Pathology and Pathobiology | Veterinary Preventive Medicine, Epidemiology, and Public Health

## Comments

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# **A Novel Educational Tool for Teaching Diagnostic Reasoning and Laboratory Data Interpretation to Veterinary (and Medical) Students**

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**Keywords:** clinical pathology, case based learning, problem solving, diagnostic reasoning, expert thinking, diagnosis, cognitive tool, teaching, learning, software design and development

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**Synopsis**

Students struggle to learn how to solve diagnostic problems. The Diagnostic Pathfinder was designed to help students learn diagnostic problem solving by supporting them in explaining relationships among history and physical exam findings, data abnormalities, and the underlying mechanisms of disease. The Pathfinder has been used to teach diagnostic problem solving to veterinary students since 2001, and is currently in use at 10 colleges of veterinary medicine. This article describes how the Pathfinder works, and summarizes research results from several studies exploring the impact of Pathfinder use on learning and satisfaction. Pathfinder characteristics are described in terms of their influence on cognitive load, and strategies are provided for effective implementation of the Pathfinder.

## Introduction

Readers of *Clinics in Laboratory Medicine* no doubt share an interest in laboratory science and clinical pathology, but it is likely that few of us dreamed of becoming laboratorians while growing up. More often, interest in clinical pathology is piqued by particular courses or instructors or when we discover the compelling power of laboratory data to uncover and clarify hidden disease. Experienced diagnosticians, veterinarians, and physicians, their expertise developed over years of diligent study and practice, become increasingly adept at learning to trace back through a cascade of data abnormalities, using logic to connect them to underlying mechanisms of disease, and ultimately identifying failing organ systems. We also learn to value data that assures us of healthy organ function. It can provide immense satisfaction to use our diagnostic reasoning skills to uncover answers hidden in laboratory data and by doing so, provide a rational foundation for effective treatment, often sparing our patients pain, suffering, and invasive additional diagnostic procedures.

It takes many years of deliberate practice to become an expert in complex disciplines.[8] Articles spanning four decades have explored how expert diagnosticians develop their expertise, how they think, and how best to teach diagnostic reasoning [1-4,9-11,15,16,18]. In a recent extensive review of this research, Norman [14] shows how this inquiry has generally shifted from an exploration of general problem-solving strategies, to how and what diagnosticians remember, to mental representations of knowledge. The outcome has been inconclusive, leading Norman to declare that that “there is no such thing as clinical reasoning; there is no one best way through a problem” (p. 426). Considering the complexity of laboratory medicine, and understanding expertise in this area, it is easy to appreciate the amount of time and effort needed for mastery. I (HSB) started to truly appreciate the difficulty of developing expertise in laboratory medicine when first attempting to teach novices (ie, students) the art and science of clinical pathology in the early 1980s. My experience in teaching a course to second-year veterinary students was the genesis of the Diagnostic Pathfinder, a software tool designed by our research group to help students learn to interpret laboratory data. Today, the Diagnostic Pathfinder is used by clinical pathology faculty at 9 veterinary schools in the US and Canada, as well as a veterinary school in Italy. It also has been adapted to teach clinical pharmacology, toxicology, and parasitology at our institution. The Diagnostic Pathfinder also has strong applicability for teaching medical students laboratory data interpretation.

The goal of this article is to first outline the barriers to learning laboratory data interpretation; then, to outline the Diagnostic Pathfinder, and how it addresses each of these barriers; third, we will present the theoretical underpinnings of the Diagnostic Pathfinder, providing evidence that supports its value in the cognitive process of diagnostic reasoning. We invite readers to contact us for more information about the Diagnostic Pathfinder.

## Teaching and Learning the Process of Laboratory Diagnosis

Laboratory diagnosis is taught in many different courses and settings in both veterinary and medical curricula. Some curricula start with an introductory course in clinical pathology and in other programs laboratory diagnosis is integrated into various organ systems or medicine courses. Regardless of the approach, the ultimate goal of introductory

clinical pathology courses is to facilitate proficiency in interpretation of clinical pathology data. In this article, we will focus on early courses in clinical pathology where students encounter large amounts of laboratory data for the first time and need to develop proficiency in diagnostic reasoning.

### Clinical pathology in the veterinary curriculum

Prior to the Diagnostic Pathfinder, we had a successful introductory clinical pathology course with many useful teaching strategies. Taking the lead from our mentors, my co-instructor and I designed the course around a set of approximately 100 cases of increasing complexity. With these cases (then on paper), students applied their new knowledge and practiced their diagnostic skills in realistic scenarios prior to practicing on real patients during their clinical years. Concepts of clinical pathology were first introduced in a lecture format and grounded in basic physiology and pathophysiology. We used a systems approach to introduce the key concepts of clinical pathology incrementally starting with the erythron, where after establishing a foundation in red cell physiology and health, we moved on to lectures on alterations of erythrocytes and their associated laboratory data in disease. Carefully timed homework assignments of simple cases worked on paper illustrated hemorrhage, hemolysis, anemia of renal failure etc., giving students the opportunity to apply the knowledge of erythrocyte kinetics, for example, and to build their new skills. Interactive in-class discussions of homework cases enabled students to refine their diagnostic proficiency and deepen understanding. Lectures concerning leukocytes followed the erythrocyte section and the accompanying homework cases grew in complexity. Cases targeting leukocyte concepts also included erythrocyte data as “fair game” when our paper patients afflicted by inflammatory diseases developed anemia of chronic disorders. The remaining systems were stepped-in using a similar format. We chose cases carefully to introduce new concepts incrementally, while repeating previous concepts, each time in a different case scenario; cases became progressively more complex.

### Challenges in learning diagnostic reasoning

For years, these students (novices) had watched their clinical mentors (experts) glance at laboratory reports and arrive at a diagnosis seemingly instantaneously, and they were eager to acquire similar lightning-fast analytical skills. The tie between the assigned cases and their goal of becoming diagnosticians was immediately clear, requiring little prodding or explanation from their teachers. We saw students become intensely engaged both intellectually and emotionally as they learned to formulate and communicate their diagnostic rationale.

To some students, it was a joy from the beginning as they learned to crack the code inherent in becoming a diagnostician. To many however, once the cases became challenging, it became a difficult and frustrating transition from a training system where rote memorization was the predominant learning strategy to one where complex thinking and problem solving was required. Though there was general agreement amongst students concerning the value of cases studies, the prospect of changing learning strategies after 20 or more years of academic success was excruciating for many. Students struggling with the change in learning strategies grappled with the difficult combination of high emotional engagement with the cases, and little initial success in solving them. Some were certain

that their first awkward attempts at solving cases were a litmus test indicating their dismal future as veterinary diagnosticians.

Despite assurances that their skills would surely improve with practice, and the abundance of cases to work on, those who struggled with the transition to this new learning strategy saw enormous disparity between themselves and the stars of the class who seemed to “get it” with ease. Frustration turned to anger. Some confided a resistance to even begin their homework, or at best made feeble efforts. Some students admitted a growing resentment at the panic that ensued after reading the initial history, because when they did so, the diagnosis did not pop into their minds immediately as it seemed to for their mentors. To cope with this situation, struggling students would read the history, jump to a diagnosis and *then* look at the data. Laboratory data that supported their presumptive diagnosis were included in the rationale; however, data refuting this diagnosis were often ignored. Of course, this led to more frustration when the struggling students’ diagnoses were completely and repeatedly unrelated to their instructor’s. When my co-instructor and I tried to dissuade students from this approach, they often complained about the difficulty in learning clinical pathology and wished it could be more like anatomy, where you either know a structure or you don’t. Cases with laboratory data require a different strategy; much more is involved, requiring a different approach where rote memorization is not sufficient.

#### The challenge of assessment

An important complication inherent in using case-based problem solving is that it is difficult to reward students directly with credit for keeping up with their homework. Grading detailed case solutions for 100 or more students is an insurmountable task for instructors with many competing faculty duties. However, without accountability for completing homework assignments, students tend to resort to their usual methods of learning by memorizing and cramming before exams, then often performing poorly.

In class, we reviewed the diagnostic rationale of each case the day it was due, but by then the stars were surging ahead and those who struggled were losing interest. This resulted in more anger, more resentment, and no eye contact with their instructors in the halls. However eventually, persistence paid off with seemingly countless discussions, demonstrations and alternate explanations of the diagnostic process. Predictably, each year, after about one half to two thirds of the semester had passed, clarity ultimately came. At that time, all was well and most students had gained a respectable level of proficiency. Then, without fail, several students would approach me to explain their new understanding with enthusiasm and to ask why I hadn’t ever explained how to approach the diagnostic process!

#### Meeting Educational Challenges with the Diagnostic Pathfinder

There had to be a better and less stressful way to learn for all concerned. So began a multidisciplinary partnership of extraordinary people who brought their talents and skills to build a remarkable computer program. The Diagnostic Pathfinder software emerged from the instructional process described above, and built upon its strengths. The primary goal was to approach the instructional problems described above with a well-designed solution using computer technology. The specific goals were to: 1) gate the process of

completing the homework cases, thereby preventing students from jumping to conclusions prior to evaluating all of the data, 2) require students to name all of the data abnormalities with the proper medical terminology, 3) require students to form hypotheses of the underlying pathophysiologic mechanisms in an outline format using “drag and drop” technology to place supporting data beneath each mechanism, 4) require completion of this outline prior to making a diagnosis, and 5) give students credit for submitting a solution online prior to case discussions (Table 1). Because we were unable to identify existing software that addressed these goals, we developed the Diagnostic Pathfinder.

#### Design, development and implementation of the software tool

In 1997 we formed a multidisciplinary Biomedical Informatics Research Group to create the instructional and interface design of the software and to evaluate its effectiveness on student and faculty users. The design process began with faculty and student interviews to refine and extend the vision as well as to define how to make it work as a software program. Filmed observations documented students as they created solutions for their paper cases, skipping over data and jumping to the diagnosis, thereby confirming the need to gate this process and require completeness. This front-end analysis led to the creation of paper prototypes for multiple iterations of interface design and usability testing. The software was first piloted as a homework tool by a group of 10 veterinary students at Virginia Polytechnic Institute and State University; it was used to demonstrate the diagnostic process to the entire class and to lead case discussions. The second part of the project involved dissemination of the software to clinical pathologists teaching comparable courses at veterinary schools at the University of Wisconsin, University of California-Davis, and University of Guelph. In addition, we piloted a continuing education program for veterinary practitioners at the Veterinary Information Network, an online education source.

#### A brief demonstration of the software

Participating instructors can enroll students in the Diagnostic Pathfinder via the Internet from anywhere in the world. We prefer the institutional email address as a login ID so students are readily identified by affiliation. Students download the software to their computers via a link to the Iowa State University College of Veterinary Medicine (ISU-CVM) server. The Pathfinder is a Java™ (Sun Microsystems, Inc) -based application that once installed, can run on or offline, needing to connect only for initial installation and case submission. Once logged in, the student opens a case from a list in their course. We typically assign 72 cases for homework in the clinical pathology course at the ISU-CVM.

The first window typically contains a picture of the patient and a short text description of history, signalment and physical examination findings (Fig. 1). Using the mouse, the student selects relevant data and clicks the *Record Observation* button, which causes the selected data to appear under *Observations and Data Abnormalities*. Additional observations can be recorded in a notes field or as free text. Once all the relevant physical findings are noted, the student clicks on the next tab, *Lab Data* (Fig. 2). The format of the lab data window is designed to resemble a routine clinical laboratory data report on which the default assessment for all laboratory data is *Normal*. The student starts with the basic task of identifying laboratory data values that are outside of the reference interval. Then, the student must correctly name each data abnormality using the proper medical term.



This takes very basic cognitive skills that are typically not difficult for veterinary students, but which helps them learn medical terminology. Some students report this as a good way to relieve tension associated with not yet knowing the diagnosis, as it eases them into the process of forming a diagnostic rationale. If the abnormality is named correctly, it is appended to the growing list of observations and data abnormalities. If the data abnormality is named incorrectly or misspelled, the system returns feedback requiring that the student try again and correct it. Faculty authors can allow as many synonyms as desired for the names of laboratory data abnormalities; the system will require the student to type in one of them. If the student tries three times without success, they can ask the system to show them the correct term and then type it to proceed. We elected this option so students would not become stuck at this point if they could not correctly name a data abnormality. All abnormal data must be identified and named; the system will not allow a student to jump ahead to the diagnosis prior to doing so.

Once all of the data abnormalities are assessed and named properly, the student is allowed to move on to the *Diagnostic Path Constructor* window (Figs. 3 & 4), which is where they formulate the diagnostic rationale (the *diagnostic path*) that connects data abnormalities to underlying pathophysiologic mechanisms of disease. This is the central and most important part of the Diagnostic Pathfinder. Here, the student enters a hypothesis as a *New Mechanism* to explain the underlying pathophysiologic mechanism of one or more associated data abnormalities. Mechanisms are free text and are not checked by the system for accuracy, spelling, or plausibility at this point. Each observation and data abnormality is moved into place under existing or newly named mechanisms using “drag and drop” methodology. Placement beneath and to the right of a mechanism indicates support for that mechanism or a causal relationship between mechanism and data abnormality. Related data abnormalities may be grouped under a common mechanism, providing stronger support for that mechanism. Data abnormalities may be dragged individually or in groups, and contiguous and noncontiguous abnormalities can be selected and dragged together using shift-click, control-click, or command-click combinations. Abnormalities also may be dragged in repeatedly under several alternate mechanisms if there are several alternate hypotheses. Additional mechanisms are created as needed and arranged in a hierarchical path to explain all observations and data abnormalities.

Students tie together the observations and data abnormalities into a coherent explanation based on the hypothesized pathophysiologic mechanisms (Fig. 4). Each parent-child data grouping can be collapsed and dragged as a unit, or selected as a group and dragged into place. The rationale now begins to tell a story. In the example illustrated, the apparently healthy cat is agitated, resulting in a fight or flight response that causes a release of epinephrine and results in contraction of the spleen, increased heart rate, and accelerated blood flow, mechanisms that explain the hematologic abnormalities. A novice learner trying to interpret leukocytosis without this context might have assumed an inflammatory response was present. Or concentrated urine may have been misinterpreted as a sign of dehydration. Within this context, however, the leukocyte changes make more sense as simply demargination from tachycardia and accelerated blood flow rather than as inflammation. Furthermore, without physical findings supporting dehydration, hypersthenuria is likely an incidental finding (cats are very efficient at concentrating their urine). It is important for students to learn that some laboratory findings such as amorphous urinary crystals, although noted on laboratory reports, are often not clinically

significant. This example illustrates how the *Diagnostic Path Constructor* window supports the goal of finding connections between related data, explaining the data groupings with the underlying pathophysiology, and tying together the rationale in a coherent story (diagnostic path). Unlike with paper and pencil, the student can drag the data groupings around repeatedly until the rationale makes sense, expressing the story in his or her own personal way.

Progression to making a diagnosis is contingent upon every observation and data abnormality being dragged under and thus explained by at least one mechanism. Once a student is satisfied with their case solution, they can enter a diagnosis by clicking on the *Make Diagnosis* tab. The *Diagnosis* box that appears is a free text field and is not checked for spelling or accuracy by the system. After entering their diagnosis, students click on the *Make Diagnosis* button, which freezes their solution and causes the system to reveal the instructor's *Expert Diagnostic Path* for a side-by-side comparison, while the case is fresh in the student's mind (Fig. 5). The expert solution may be color-coded by the faculty author to emphasize certain mechanisms. The student is then asked to self-assess how well her or his solution matches the instructor's solution. This self-assessment is meant only to communicate an assurance of a student's perceived competence or concern. The student also receives confirmation of on-time submission and course credit. The system awards a point for each case solution submitted on time, regardless of its quality. In-class quizzes (explained below) are used to measure mastery of the diagnostic process.

As the course progresses, cases become increasingly lengthy and complex, repeating common themes like stress leukograms and dehydration, and building incrementally as new systems are studied. Hyperlinks to photomicrographs illustrate microscopic or gross findings (Fig. 6). Cases and the expert path can also be linked to e-books, medical databases such as PubMed, websites, virtual slides, videos, and other reference material.

Three other tools support the Diagnostic Pathfinder: the Course Manager to create courses, transfer cases and enroll students; the Case Editor to facilitate and automate the tasks involved in case authoring or editing; and the Report Generator to quickly view student solutions and manage course credit.

## **Research Results and Theoretical Foundations—Why It Works**

While software tools that look nice and work as designed might be considered a useful end in and of themselves, we were committed to determining the extent to which this software actually helped alleviate the problems it was designed to address. We designed and conducted several studies to evaluate the software and the experience of students and faculty using the software[5-7].

### **Effects on student learning**

First, we wanted to answer the questions: did students learn clinical pathology better using the Diagnostic Pathfinder and was their experience more pleasant? We found that students who used the Pathfinder performed significantly better on case-based final exam questions than those who participated in curricular processes that used paper-based cases but were otherwise identical (Table 2) [5,7]. Similarly, students using the Pathfinder as a supplemental instructional strategy also outscored their counterparts participating in otherwise identical instruction[7]. Students also indicated that using the Pathfinder made

their homework more enjoyable and made learning clinical pathology easier[5,7]. These results have been consistent across thousands of students at seven veterinary colleges where evaluations have been performed one or more times (depending on the college) between 2002 and 2010.

### Mitigating the cognitive load

Second, we wanted to explore the effectiveness of the Diagnostic Pathfinder in mitigating the cognitive load imposed by the diagnostic reasoning process. Cognitive scientists have known for decades that there are predictable limits to the mind's capacity to process information. One of the best known early efforts to quantify the ability to manage cognitive load came from George Miller's landmark paper, "The Magical Number Seven, Plus or Minus Two: Some Limits on our Capacity for Processing Information"[13]. In attempting to unify a number of studies regarding what is now commonly referred to as the mind's *working memory*, Miller suggested that the mind can recall about 7 new stimuli, without re-coding (in Miller's words - *chunking*) the information in some way. Sweller[19] proposed *cognitive load theory* as a useful framework for evaluating learning tasks in light of the limitations of the mind's working memory, and in terms of the kinds of load that those learning tasks impose on cognitive processes. Given best available current estimates of working memory limitations, cognitive load theorists work under the assumption that working memory can hold no more than five to nine information elements, and can actively process no more than two to four elements simultaneously.[21]

Theoretically, there are three kinds of load that might be involved in a learning task. *Intrinsic* load is the inherently irreducible requirement of a specific cognitive task. Intrinsic load cannot be reduced without changing the task itself. For example, for an experienced clinician, diagnosing and developing a treatment protocol for a patient with hyperadrenocorticism might be easily accomplished with very little effort, and therefore have very little intrinsic load. A veterinary or medical student might find the same task insurmountable unless it is simplified (changed) in some way. Such a change might entail reducing the task to manageable pieces (first considering history, then carefully examining laboratory data with reference to notes, then reviewing the pathophysiology of suspected diseases, and so forth.) As the student becomes more capable, the intrinsic load of diagnostic problem solving for familiar cases/conditions is reduced for that student. *Extraneous* cognitive load comes from tasks that are irrelevant to or unnecessary in accomplishing the learning task. Poor, incomplete, or inaccurate explanations, distractions, etc., impose extraneous cognitive load. *Germane* cognitive load channels cognitive resources in helpful directions for learning. Clear explanations and relevant practice tasks are examples of teaching interventions that might provide germane cognitive load.

We posited that the Diagnostic Pathfinder helps students learn the difficult task of integrating clinical laboratory data by reducing extraneous cognitive load and introducing germane cognitive load. There can be little doubt that integrating clinical laboratory data to explain even a simple clinical case imposes considerable cognitive load on veterinary and medical students. They must simultaneously consider multiple disruptions in different organ systems, many potential disease processes, and, in the case of veterinary students, comparative information for multiple species. The specific ways in which we believe this is

accomplished has emerged through analysis of survey data from hundreds of students and interviews with faculty[6].

First, the Pathfinder provides detailed, relevant feedback at the moment of highest interest to students—just as they have finished working through the problem, when their own solution is fresh in their mind. While the benefit of feedback is well documented[12,17] seeing a solution to the problem in the same format as their own solution and at the moment of highest engagement imposes germane cognitive load that is particularly powerful.

Second, the Pathfinder gates the learning task. Students first identify abnormal data and name the abnormality correctly—then they explain it. All data must be identified before it is explained, and all data must be explained before it is compared to the expert solution. This strategy reduces the intrinsic cognitive load of the overall learning task, allowing students to master these skills and combine knowledge and skills into integrated conceptual units (chunks) for later use[20]. Our studies[5,7] showed that the learning benefits achieved while using the Pathfinder were demonstrated under circumstances in which the gating requirement was no longer present (ie, taking a final exam on paper). This suggested that the individual tasks were indeed chunked during learning, and the Pathfinder was not simply functioning as a “crutch” or aid.

Third, data manipulation is easy via the drag-and-drop interface. Students can easily “try out” multiple explanations, playing with the data until it says what they want it to say. This feature is likely to reduce the extraneous cognitive load imposed by manipulating data in less flexible formats (such as paper).

Fourth, the Pathfinder environment is “safe” for students to engage with the problems without fear of making an embarrassing and/or high-stakes mistake. To the extent fear of mistakes or failure imposes extraneous cognitive load, it can divert students from the goal of learning.

Finally, while not an objective of our study, we found that sequencing cases from simple to more complex was instrumental in managing the intrinsic cognitive load when learning how to interpret laboratory data.[21]

## **Classroom Implementation Strategies**

Our university partners have implemented the Pathfinder in many different ways. The number of cases used in a single course has varied from 5 to 108. The Pathfinder has been implemented in both core courses and supplemental electives. Cases have been integrated into lecture and laboratory settings, and have been used for instruction with introductory students, fourth year students, residents, and practicing veterinarians. Pathfinder cases have been used for homework, in-class practice activities, and testing. Most instructors have used existing cases and solutions but some have entered their own solutions, and still others have authored extensive sets of their own cases and solutions. While Pathfinder implementations have varied, all instructors have chosen to sequence cases beginning with simple cases initially and gradually increasing case complexity, with later cases that usually repeat and build upon themes introduced in earlier cases.

One recent major adaptation of Pathfinder use in our course at Iowa State University involved the addition of team based learning (TBL) strategies. TBL is intended to engage students who are using the Pathfinder in helping each other gain skills in diagnostic

reasoning. The TBL strategy uses teams of six students each, some of which engage from a satellite location in Nebraska via two-way video technology. Approximately six Pathfinder cases are assigned per week as homework, following pertinent lecture material; two cases are due at the beginning of each case discussion session and a third new case is assigned as an in-class quiz. The third case has similar learning objectives as one of the homework assignments but is set in a different scenario or involves a different species. For example, the homework assignment following lectures on hemolytic anemia includes a case of a cat with extravascular hemolysis due to *Mycoplasma hemofelis* infection and a case of a horse with an intravascular hemolysis from red maple poisoning. The quiz on the following day is a case of a dog with extravascular immune mediated hemolytic anemia. As part of the quiz, students answer 5 multiple-choice questions designed to probe deeply into their understanding of the various pathophysiologic mechanisms underlying hemolysis. The students first take the quiz individually and then again with their team. Both the individual and the team scores contribute to their grade. Team quizzes are animated and lively, as team members must arrive at a consensus solution; when doing so, they teach each other complicated concepts while communicating and convincing one another of the intricacies and correctness of their solutions.

### **Our Future in ThinkSpace**

The Diagnostic Pathfinder has strong potential to facilitate learning in multiple disciplines, as well as in advanced clinical pathology courses, residency training programs, and as continuing education for veterinary practitioners. We are currently partnering with faculty in fields as diverse as toxicology, parasitology, pharmacology, internal medicine, anatomic pathology, materials science engineering, physics, horticulture, and geology, both to re-engineer the Pathfinder and to combine it with other software into a more flexible and extensible learning tool. ThinkSpace is open source software based on Google Web Toolkit technology (Google, Inc. Mountain View, CA). The ThinkSpace interface will allow authors to add differential diagnoses, give students the ability to select tests, and add the option to choose treatments. These expanded functionalities will enhance the applicability of the Pathfinder to other courses where diagnostic reasoning is taught.

### **Conclusions**

Several studies have shown that use of the Diagnostic Pathfinder is associated with improved performance and student satisfaction. The Pathfinder helps learners compensate for the difficulty inherent in diagnostic problem solving by assisting them in managing cognitive load: gating the process, providing for easy manipulation of many conceptual elements in the diagnostic path, and providing timely and relevant feedback. The Pathfinder has been used successfully in a variety of settings and contexts. While those implementations have varied, all share a common sequencing of cases from simple to complex, with later cases building on information contained in earlier cases.

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Table 1. Main instructional challenges in interpreting laboratory data and how they are addressed by the Diagnostic Pathfinder.

<b>Instructional Challenge</b>	<b>Pathfinder Element to Address the Challenge</b>
Students jump to conclusions prior to evaluating all the data	Gate the process of completing cases; students must identify and name data abnormalities and then complete their rationale prior to making a diagnosis
Students must learn new vocabulary, especially in an introductory class	Require students to name all data abnormalities using proper medical terminology
Students struggle to make connections between seemingly disparate clinical findings, data abnormalities, and pathophysiologic mechanisms of disease	Require students to form hypotheses of the underlying pathophysiologic mechanisms in an outline format using “drag and drop” technology to place supporting data beneath each mechanism
Students need incentive (credit) to engage in meaningful practice	Give students credit for submitting a solution online prior to case discussions in the classroom

Table 2. Differences in percentage final exam scores obtained by students using the Diagnostic Pathfinder compared with control students at three different institutions.

<b>Study Design</b>	<b>Pathfinder Mean (n)</b>	<b>Control Mean (n)</b>	<b>P- value*</b>	<b>Effect Size**</b>	<b>Reference</b>
Pathfinder vs. paper-based control (Institution 1)	87.3 ± 10.1 (n = 173)	81.6±9.8 (n = 334)	< .0005	0.58	5
Pathfinder vs. paper-based control (Institution 2)	90.1 (n = 126)	85.0 (n = 120)	< .0005	0.70	7
Pathfinder as a supplement (Institution 3)	87.0 (n =113)	84.7 (n = 199)	.002	0.36	7

\*Independent Samples t-test; \*\*Cohen's d

## Figure Legends

Fig. 1. The first window of a case in the Diagnostic Pathfinder. Students select relevant history, signalment, and physical examination findings, which then appear in the right-hand column under *Observations and Data Abnormalities*, where they are identified with an “H” for history.

Fig. 2. The *Lab Data* window. Test names are abbreviated on buttons, which can be clicked to reveal the full name of the test. Pull-down menus are used to assess data as Normal, High, or Low. Correct assessment causes the cursor to jump into an Abnormality Name box where the appropriate medical term must be typed in and spelled accurately. Correctly named data abnormalities are automatically added to the list in the right-hand window where they are identified with a “D” for data.

Fig. 3. The *Diagnostic Path Constructor* window. Students enter a hypothesis as a mechanism to explain the observations and data abnormalities. A New Mechanism can be dragged into place from the right side or can be created by right clicking in the appropriate area on the left or by using a button on the toolbar. The diagnostic path in the left window is created by the “drag and drop” of elements from the right window by holding down the mouse button on the blue square. In this case, “splenic contraction” is the mechanism (M) hypothesized to explain two data (D) abnormalities, erythrocytosis and thrombocytosis. As each data abnormality is dragged into place, it is checked off on the list to the right.

Fig. 4. The *Diagnostic Path Constructor* window showing a completed diagnostic path. In this example, a “fight or flight response” (epinephrine release) accounts for the physical findings of agitation and nervousness and is supported by the lack of other clinical abnormalities. The splenic contraction data grouping has been dragged beneath the physical findings; the splenic contraction and leukocyte data groupings are related to the physical findings by the intervening mechanism of epinephrine release. The urinary data abnormalities are grouped separately, since they can be observed in otherwise healthy cats.

Fig. 5. The *Expert Diagnostic Path* window. After students submit their Diagnosis they receive immediate expert feedback. Their diagnostic path/case solution (on the right) is shown side-by-side with the instructor’s (expert) solution (on the left).

Fig. 6. Photomicrographs and other resources can be linked to the cases. In this example, an image of neutrophils with intracellular bacteria is linked to the microscopic description of an exudate in an animal with an effusion.

## Figures

Case 7 Diagnostic Pathfinder

Course ISU VPTH 425, 2010 T...

Signalment/History/Physical Exam Lab Data Construct Diagnostic Path Make Diagnosis Expert Diagnostic Path Submit For Credit

### CASE 7




Image contributed by Dr. Elizabeth Welles

Your most loyal and conscientious feline breeder presents a five year old, female spayed domestic short hair cat for routine examination. He claims that this cat has great potential as a very successful breeding animal and asks you to perform a thorough health screen. On physical examination, the cat is very nervous and tries to escape at every opportunity, but no abnormalities are found. She becomes extremely agitated as you and your technician attempt to obtain blood for a CBC. You pry a left front claw out of the back of your hand after a successful venipuncture.

Record Observation

#### Observations and Data Abnormalities

<input type="checkbox"/>	H	v	five year old, female spayed domestic short hair cat she looks really angry!
<input type="checkbox"/>	H	>	routine examination
<input type="checkbox"/>	H	>	perform a thorough health screen
<input type="checkbox"/>	H	>	cat is very nervous and tries to escape at every opportunity
<input type="checkbox"/>	H	>	no abnormalities are found

Figure 1

Case 7 Diagnostic Pathfinder

Course: ISU VPTH 425, 2010 T...

Signalment/History/Physical Exam **Lab Data** Construct Diagnostic Path Make Diagnosis Expert Diagnostic Path Submit For Credit

### HEMATOLOGY

TEST NAME	TEST RESULT	SPECIES FELINE	REF INT	UNITS	ABNORMALITY NAME
RBC	11.00	High	5.0–10.0	n <sup>o</sup> 10 <sup>6</sup> /ul	erythrocytosis
HGB	16.5	High	8.0–15.0	g/dl	erythrocytosis
HCT	47.0	High	30.0–45.0	%	erythrocytosis
MCV	42.7	Normal	39.0–55.0	fl	
MCH	15	Normal	13.0–17.0	pg	
MCHC	35.1	Normal	30.0–36.0	g/dl	
NRBC		Normal	0	n/100 wbc	
ANISO		Normal			
POLYCHR		Normal			
HYPOCHR		Normal			
POIK		Normal			
WBC	25.4	High	5.5–19.5	n x 10 <sup>3</sup> /ul	leukocytosis
SEG	60%	Normal	2.5–12.5	n x 10 <sup>3</sup> /ul	
BAND	0	Low	0.0–0.3	n x 10 <sup>3</sup> /ul	

### Observations and Data Abnormalities

- five year old, female spayed domestic short hair cat she looks really angry!
- routine examination
- perform a thorough health screen
- cat is very nervous and tries to escape at every opportunity
- no abnormalities are found
- She becomes extremely agitated
- erythrocytosis
- leukocytosis

Figure 2

Case 7 Diagnostic Pathfinder

Signalment/History/Physical Exam Lab Data **Construct Diagnostic Path** Make Diagnosis Expert Diagnostic Path Submit For Credit

Course ISU VPTH 425, 201

**Observations and Data Abnormalities**

**Signalment/History/Physical Exam**

**M** **>** splenic contraction

**B** **D** **>** erythrocytosis

**B** **D** **>** thrombocytosis

**Observations and Data Abnormalities**

**M** **>** New Mechanism

**H** **>** five year old, female spayed domestic short hair cat

**H** **>** routine examination

**H** **>** perform a thorough health screen

**H** **>** cat is very nervous and tries to escape at every opportunity

**H** **>** no abnormalities are found

**H** **>** becomes extremely agitated

☒ **D** **>** erythrocytosis

**D** **>** leukocytosis

**D** **>** neutrophilia

**D** **>** lymphocytosis

☒ **D** **>** thrombocytosis

**D** **>** cloudy urine

**D** **>** hypersthenuria

**D** **>** amorphous crystalluria

Figure 3

Case 7 Diagnostic Pathfinder

Course ISU VPTH 425, 2010 T...

Signalment/History/Physical Exam Lab Data **Construct Diagnostic Path** Make Diagnosis Expert Diagnostic Path Submit For Credit

**Construct Diagnostic Path**

A - M > fight or flight response

B H > five year old, female spayed domestic short hair cat

B H > cat is very nervous and tries to escape at every opportunity

B H > becomes extremely agitated

B - M > no abnormalities are noted on history or physical examination

C H > perform a thorough health screen

C H > routine examination

C H > no abnormalities are found

C - M > epinephrine release

D - M > splenic contraction

E D > erythrocytosis

E D > thrombocytosis

E - M > increased heart rate

F - M > accelerated blood flow

G - M > marginal pool leukocytes enter circulating pool

H D > leukocytosis

H D > neutrophilia

H D > lymphocytosis

A - M > in this context, may be consistent with health

B D > cloudy urine

B D > hyperthenuria

B D > amorphous crystalluria

**Observations and Data Abnormalities**

M > New Mechanism

H > five year old, female spayed domestic short hair cat

H > routine examination

H > perform a thorough health screen

H > cat is very nervous and tries to escape at every opportunity

H > no abnormalities are found

H > becomes extremely agitated

D > erythrocytosis

D > leukocytosis

D > neutrophilia

D > lymphocytosis

D > thrombocytosis

D > cloudy urine

D > hyperthenuria

D > amorphous crystalluria

Figure 4

Case 7 Diagnostic Pathfinder

Course ISU VPTH 425, 2010 T...

Signalment/History/Physical Exam Lab Data Construct Diagnostic Path Make Diagnosis Expert Diagnostic Path Submit For Credit

**Expert Solution**

**DIAGNOSIS:** fear and excitement reaction

**DIAGNOSTIC PATH:**

[M(F)] **EXCITEMENT AND FEAR REACTION**

[H] five year old, female spayed domestic short hair cat

[H] routine examination

[H] perform a thorough health scree

[H] the cat is very nervous and tries to escape at every opportunity

[H] She becomes extremely agitated

[H] You pry a left front claw out of the back of your hand after a succ

[M(F)] **NO ABNORMALITIES ON PHYSICAL EXAMINATION**

[H] no abnormalities are found

[M(R)] **EPINEPHRINE RELEASE**

[M(R)] **SPLENIC CONTRACTION**

[D] erythrocytosis

[D] thrombocytosis

[M(C)] **TACHYCARDIA**

[M(C)] **INCREASED HEART RATE AND BLOOD PRESSURE**

[M(C)] **INCREASED BLOOD FLOW**

[M(C)] **DEMARGINATION OF LEUKOCYTES**

[D] leukocytosis

[D] neutrophilia

[D] lymphocytosis

[M(F)] **CLINICALLY INSIGNIFICANT FINDINGS**

[D] cloudy urine

[D] hypersthenuria

[D] amorphous crystalluria

**Key:**

M(C) = Core Mechanism - mechanism central to this case.

M(R) = Review Mechanism - mechanism reviewed in this case.

M(F) = Framing Mechanism - mechanism supporting this case.

**Your Solution**

**DIAGNOSIS:** fight or flight response

**DIAGNOSTIC PATH:**

[M] **FIGHT OR FLIGHT RESPONSE**

[H] five year old, female spayed domestic short hair cat

[H] cat is very nervous and tries to escape at every opportunity

[H] becomes extremely agitated

[M] **NO ABNORMALITIES ARE NOTED ON HISTORY OR PHYSICAL EXAMINATION**

[H] perform a thorough health screen

[H] routine examination

[H] no abnormalities are found

[M] **EPINEPHRINE RELEASE**

[M] **SPLENIC CONTRACTION**

[D] erythrocytosis

[D] thrombocytosis

[M] **INCREASED HEART RATE**

[M] **ACCELERATED BLOOD FLOW**

[M] **MARGINAL POOL LEUKOCYTES ENTER CIRCULATING POOL**

[D] leukocytosis

[D] neutrophilia

[D] lymphocytosis

[M] **IN THIS CONTEXT, MAY BE CONSISTENT WITH HEALTH**

[D] cloudy urine

[D] hypersthenuria

[D] amorphous crystalluria

Figure 5



Case 72 Diagnostic Pathfinder

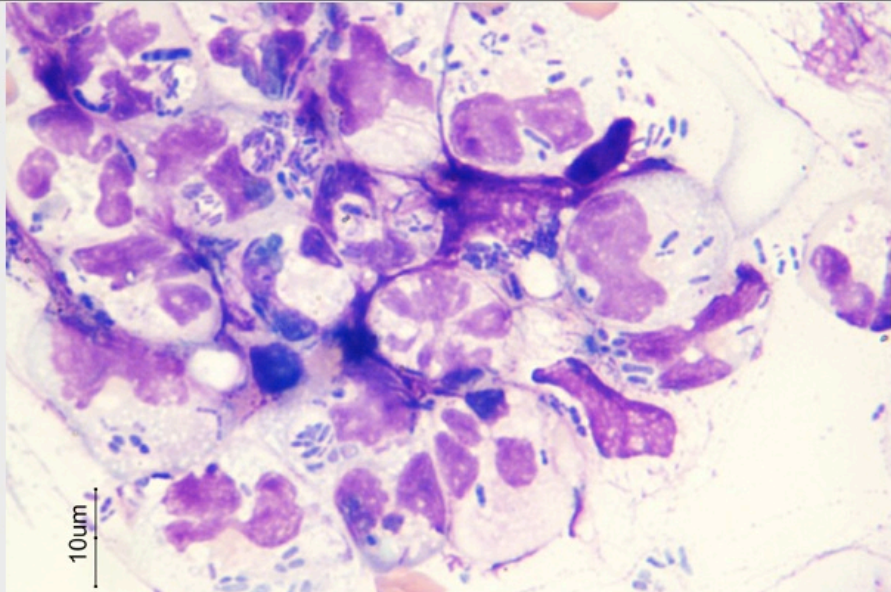
Signalment/History/Physical Exam Lab Data Construct Diagnostic Path Make Diagnosis Expert Diagnostic Path

PRO 4.5 g/dl

DESCRIPTION

Microscopic Description: Nucleated cells are exceedingly numerous with most being degenerate or nondegenerate neutrophils. Macrophages are scattered. [Mesothelial cells](#) are seen in low numbers. Red cells are plentiful. [Bacteria of a mixed population \(rods and cocci\)](#) are present in moderate numbers. Some neutrophils contain [phagocytized bacteria](#).

Mixed Intracellular and Extracellular Bacteria



**Mixed Intracellular and Extracellular Bacteria**

Bacterial rods and cocci of various sizes are present within and outside of cells.

Figure 6